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Title: ***"Biomechanics of Human Movement in Occupational Tasks with Ergonomic Considerations"***

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Biomechanics of human movement in occupational tasks with ergonomic considerations

Biomechanics is a multidisciplinary activity that requires combining knowledge from engineering and physical sciences. The biomechanics of human movement is defined as the mechanics and biophysics of the musculoskeletal system [1]. The role of neural system is also there but limited to electromyography (EMG) and its relationship to the mechanics of the muscle. Kinematic variables, kinetic variables and electromyograms are mainly used in the description and analysis of human movement. The discipline of biomechanics concerning with the study of human disorder and performance limitations that are caused by the mismatching of human physical capacities and human manual performance requirements in industry is termed as occupational biomechanics [2]. The biomechanics of human movement in occupational tasks deals with describing, analyzing, and assessing human movements in physical interaction of workers with their tools, machine and material so as to enhance the workers' performance while minimizing the risk of musculoskeletal disorders.

A wide variety of physical movements are observed in various occupational tasks ranging from repetitive hand or arm movements to the lifting of a load to the pushing or pulling a load to a distance. The physical and biological principles are less or more same in all cases. However specific movement tasks and the level of details change from case to case form the point of view of the performance of each movement. At the basic level, the name given to science dedicated to the broad area of human movement is kinesiology [1]. It is important to mention that the variables that are measured and analyzed in human movement are usually available in the time domain (e.g., forces, displacements, accelerations, moments etc.), i.e. these are there in the signal form. The characteristics of these signals help in exploring more complex total limb and total body motor patterns. Kinematic variables involved in the description of the movement include linear and

angular displacements, velocities and accelerations. The displacement data are noted down from anatomical landmarks which are centre of gravity of body segments, centre of rotation of joints, extremes of limb segments, and key anatomical prominences. Relative or absolute spatial reference system is employed. Relative angles involve joint angles; absolute angles are referred to the external spatial reference. Kinetic variables include internal and external forces that cause the movement. Internal forces are caused by muscle activity, ligaments, or the friction in the muscles and joints. External forces are generated from the ground or from external loads, from active bodies or from passive sources. Kinetic variables include the moments of the force produced by muscle crossing a joint, the mechanical power and the energy changes of the body that result from this mechanical power. The neuromuscular system consists of many muscles, which contain many motor units. Each motor unit has a nerve innervating a collection of muscle fibers [3]. The neural control of movement cannot be separated from the movement itself, and in the electromyogram we have information regarding the final control signal of each muscle. The EMG is the primary signal to describe the input to the muscular system. It gives information regarding which muscle or muscles are responsible for a muscle moment or whether antagonistic activity is taking place. Because of the relationship between a muscle's EMG and its tension, a number of models have evolved. The EMG also has information regarding the recruitment of different types of muscle fibers and the fatigue state of the muscle.

Ergonomics is the science of fitting workplace conditions and job demands to the capabilities of the working population. It is closely associated with occupational biomechanics [4]. Prolonged physical activities are liable to introduce risks for low back pain and injury due to the adapted neuromuscular response of the system owing to the neuromuscular fatigue [5]. Neuromuscular fatigue can modify the myoelectric activity of the muscles during acute activities especially in awkward postures. Biomechanically, muscular fatigue is considered as a reduced capacity of the muscle to maintain a specified force output. The neurophysiology and biomechanics, together, help in specifying the

level of fatigue within the system. The neuromechanical relationship assists in determining how the body will perform during different occupational activities such as pushing and pulling. If the neuromuscular fatigue is present in individuals, who perform dynamic movement over sustained periods of time, it can cause reduced motor functioning.

Some of the important risk factor associated with work-related musculoskeletal disorders (WMSDs) are repetitive, sustained, forceful movements of the hand and wrist. Kong et al. [6] has presented the recent studies which show that repetitive wrist motion is a major risk factor for WMSDs in various contexts. Wrist and tendon dynamics are also the contributory factors. Biomechanical models estimating the effects of wrist dynamics on internal tendon force as a theoretical basis for the risk of incurring a WMSD have been presented. These biomechanical models utilize either the reduction method or the optimization method to solve the indeterminate problem resulting from too many internal variables. High tendon forces combined with wrist dynamics is a contributing factor in causing WMSDs.

Workplace characteristics and task demands can compel workers to assume a kneeling or squatting posture in the performance of their work. Gallagher et al. [7] did one such study for underground coal miners who work in low-seam mines and frequently handle materials in kneeling or squatting postures. To assess quadriceps and hamstring muscle demands in these postures, EMG data were collected. EMG activity was noted down throughout the transfer of quadriceps muscles and hamstring muscles of each thigh. Results showed that EMG data for thigh muscles were affected by an interaction between posture and angular position of the load lifted. Muscles of right thigh were found to be most active while lifting a block from the participant's right and activity slowed down as the block was transferred to the left. There was a reverse pattern in the muscles of left thigh. EMG signal of thigh was found to be least in postures with fully flexed knees, that is why workers prefer this posture. Examination of the EMG signals of the muscles

provide insight into the job demands experienced in various postures and the trade-offs that occur as various postures are assumed. The above study also suggested that kneepads do not significantly affect EMG signal and, thus, they seem not to produce any decrement in terms of increased EMG activity and energy cost. An interesting result of the analysis indicated that the peak EMG signal for the thigh muscles was inversely related to the base of support provided by the assumed posture.

Job related physical and psychosocial factors are normally associated with low back disorders. Among the WMSDs, scientific data indicates manual lifting as a strong predictor of the development of low back pain at work. Hoozemans et al. [8] quantified the effects of lifting height and mass lifted on the peak low back weight in terms of moments, compressive forces and shear forces. Low back loading was measured by a 3-D linked segment dynamic model and a complete EMG based model. A regression technique for correlated data was used to evaluate the effect of height and mass. An increase in lifting height and reduction in lifting mass were correlated to reduce low back load. Trunk flexion is observed as a main contributor in low back load. Ergonomic considerations suggest to prioritize optimization of the vertical location of the weight to be lifted rather than reducing the mass of the load for handle heights between 32 cm and 155 cm, and for load masses between 7.5 to 15 kg. Lifting height and lifting mass were found to be significant determinants of low back load during manual materials handling. It explained the quantitative effect of lifting height and mass lifted, the outcomes of which can be utilized by ergonomists at the work place to decide for lifting height and load mass.

The dynamics of a lifting motion in an occupational task affect the spine loading and the risk of low back disorder. The influence of a quick lifting motion (i.e. trunk extension) can increase the net load force and thus have a direct influence on moment about the spine and spine loading. The effects of occupation low back pain are significant. It has been reported that $ 8.8 billion was spent on occupational low back pain claims in the

USA in 1995 and the rate of LBP claims was 1.8 per 100 workers per year [9]. Various epidemiological studies have demonstrated an association between low back disorder and job requirements, including heavy and frequent lifting, awkward and prolonged postures, trunk dynamics in lifting and whole-body vibration. Investigating the relationship between these high risk job requirements and the fundamental low back biomechanics can offer insight into the mechanism of injury and evidences as to suitable ergonomic consideration for the avoidance of occupation low back pain. Dai et al. [9] studied lifting loads having a horizontal velocity (lifting from a conveyor). The inertial characteristics of these loads affect lifting technique and low back stress. Results revealed that increasing horizontal load speed from 0 m/s to 2.4 m/s resulted in (1) an increase in peak sagittal angle (73° vs. 81°), a decrease in levels of peak sagittal plane angular acceleration (480° / S^2 vs. 4° / S^2) and peak transverse plane angular acceleration (200° / S^2 vs. 140° / S^2) and an increase in trunk muscle co-activation.

A study by Kingma et al. [10] revealed that weight lifters' technique (WLT), characterized by a wide foot placement, moderate knee flexion and a straight but not upright trunk, turns out to be superior to free, squat and stoop lifting technique while lifting a wide box at handles. In this study, net moments are measured using a 3-D linked segment model. Spinal forces are calculated using an electromyographic-driving trunk model. While lifting the wide box at the bottom, none of the lifting techniques turned out to be clearly superior to others.

A good posture is a state of musculoskeletal balance that involves a safe amount of stress or strain to the body. Deviation from normal alignment are not uncommon in many occupational tasks. A study by Kim et al. [11] tested the consequences of three different types of backpack on head posture and neck muscle EMG. The four loading conditions were examined: no pack; a backpack; a double pack; and a modified double pack (backpack and front pack weighed 10% and 5% of body weight, respectively). Neck muscle activity, forward head angle and forward head distance (the perpendicular

distance from C7 to a vertical line through the tragus of the ear) are dependent variables in this work. This study was done on fifteen subjects who walked at a speed of 0.8 m/s on a treadmill. The EMG activity of muscles and the forward head angle and forward head distance were all considerably higher when holding a backpack than for the other conditions. The forward head angle and forward head distance decreased while carrying a modified double pack. Modified double pack minimized postural deviation.

An inversion platform is widely used to model the kinematics of muscle injury in ankles. The model has a small platform with trap doors that fall to a restricted position. Hopkins et al. [12] compared muscle reaction time and magnitude of muscle activity following sudden ankle inversion in standing and walking. The walking condition offer lesser reaction times and larger amplitudes when compared with standing condition. In comparing the reaction times and EMG amplitudes involving walking and standing situations, the forces acting on the concerned leg are very diverse. The standing condition generates a vertical force with the foot in a neutral position, whereas the walking condition extracts forces in the anterior and vertical directions with the foot moving from a supinated position into inversion at neutral. The subject move ahead (heel strike to midstance) into inversion when perturbed through walking, so the time was somewhat reliant on the speed of gait and the regular transition of the subjects' body mass (loading) to the concerned foot. A considerable difference in latency values involving the standing and walking conditions was noticed. Hopkins et al. [13] demonstrated changes in ankle dynamic restraint (peroneal short latency response and muscle activity amplitude) through inversion perturbation following ankle joint cryotherapy. Cryotherapy continues to be a well-liked intervention in the management of acute and chronic musculoskeletal conditions. It has been promoted for its positive effects on pain, mediation of the inflammatory process, and decrease of secondary injury [14]. Cooling muscle tissue shows to have distinct physiological effects on muscle contraction, with depressed muscle spindle activity [15], reduced ATP-hydrolysis, and impaired calcium liberate and uptake in the muscle [16].

Biomechanics of human movements has a large number of applications in other related areas such as rehabilitation engineering, sports engineering and exercise physiology which have a direct bearing on research issues in the area of safer occupational tasks.

Whiting et al. [17] showed that activation of the upper and lower portions of the rectus abdominis and external oblique were manipulated by whether the subjects performed a traditional, oblique and reverse crunch. Sit-up exercises are used broadly to advance abdominal strength. The aim of programs designed to make stronger the abdominal muscles consist of performance enhancement, postural improvement, and decreasing the risk of low back pain. The relation between low trunk muscle strength and low back pain is well recognized [18-20]. Poor trunk muscles and decreased flexibility of the back and hamstrings are recognized as risk factors in the reappearance of chronic low back trouble [21]. Exercise programs are effective in remedying muscle weakness by improving abdominal strength [22-27]. Facts also recommend that exercises may stop low back pain in individuals [28]. Electromyographic measurement of anterior trunk muscles, mainly the rectus abdominis (RA), has been well reported across a range of activities, including lifting [29] and different types of sit-up exercises [30-37]. The external oblique (EO) supports the RA in controlling spinal flexion and extension [38] and, in performance with the internal oblique, facilitates trunk rotation [22]. McGill [38] showed that the contribution of the obliques to flexion may be undervalued and that these muscles may play a better role in flexion than earlier recommended.

Most of studies related to sit-up exercises have utilized EMG to express movement dynamics. Other studies have detailed out muscle joint moments and physiological measures [39, 40] and spinal loading [41] during sit-ups. Moraes et al. [42] described the activation of the rectus abdominis, obliquus externus and rectus femoris muscles during the crunch abdominal exercise carried out with weights using surface electromyography.

Muscle activation while performing unstable and stable types of resistance exercises show diverse outcomes. McCurdy et al. [43] compared the EMG activity of the external oblique muscle in athletes using the bilateral and modified unilateral squat. Kushion et al. [44] compared the muscular activation of the vastus medialis oblique (VMO), vastus lateralis (VL), and the VMO/VL ratio across four general rehabilitation exercises: straight leg raise with neutral (SLRN) and externally rotated (SLRER) hip positions, and short arc quads with neutral (SAQN) and externally rotated (SAQER) hip positions. No considerable difference was observed for the VMO/VL ratio across the four exercises.

In the proposed research work we propose to meet the following objectives based on above-mentioned literature survey:

1. To identify certain occupational tasks in nearby region which involve difficult human movements. The difficulty can be in terms of prolonged awkward postures, handling heavy load, repetitive hand/wrist movements, forceful exertions or working environment.
2. To measure and describe human movements in the identified tasks in terms of required kinematic variables and kinetic variables. We also intend to analyze relevant signals in the movements such as signals of forces, displacements, accelerations, moments etc.
3. To carry out the EMG analysis of human movements in the tasks selected involving study of electromyograms which have information regarding the final control signal of each muscle. We may also determine the fatigue state of muscles involved in different movements.
4. To characterize workers' capability to carry out identified occupational tasks using physiological approach.
5. To develop quantitative models to summarize and explain the investigations documenting human capacity and job demands.

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